Components for 5G – what is new?

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ROHDE&SCHWARZ

Agenda

- 5G NR – a very brief introduction
- From technology to component
- Test solutions - conducted to OTA

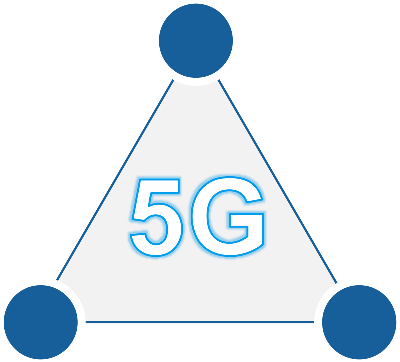
5G NR – introduction

The Triangle of 5G Use Cases

eMBB remains Priority 1

Massive IoT

- A diverse ecosystem (operators, manufacturers, local authorities, certification only for some technologies)
- Mix of technologies (GSM, Lora, Zigbee, WLAN, Bluetooth, Cat M, NB-IoT,…)
- It’s all about cost efficiency and massive connectivity



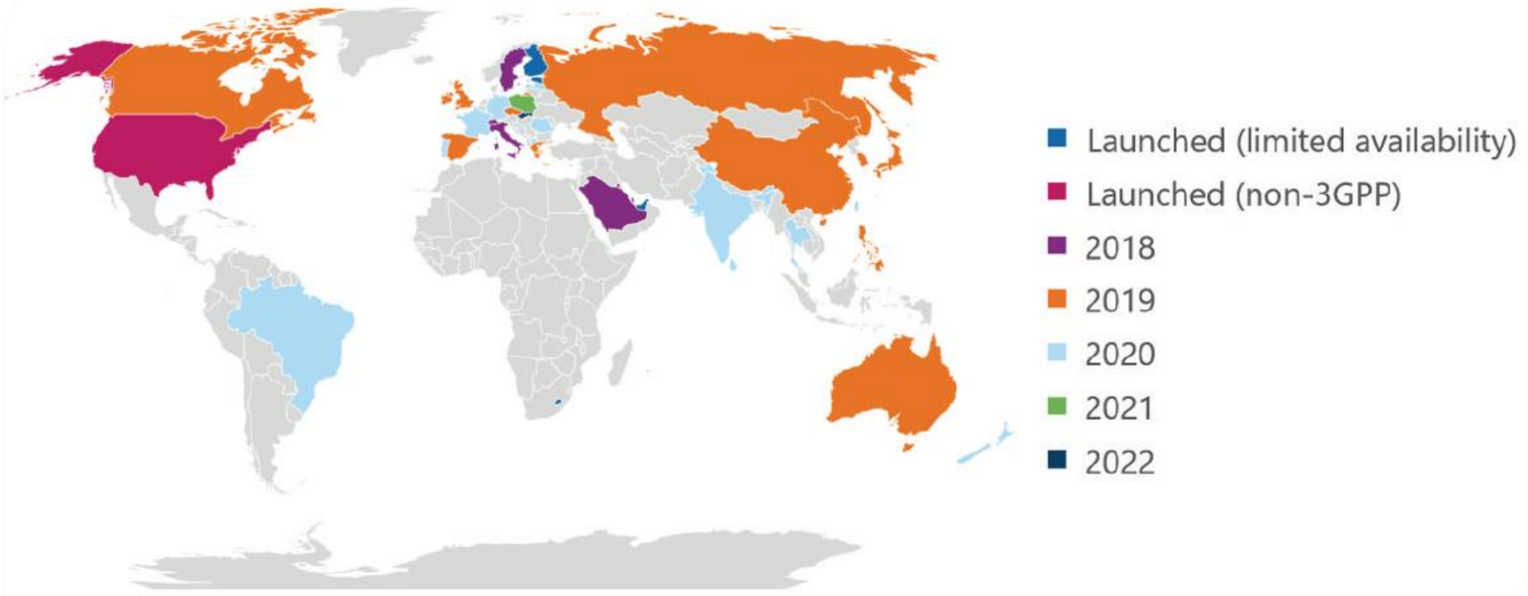
eMBB – the known playground

- Established ecosystem (operators, manufacturers, certification of devices)
- Evolution from existing technologies (LTE-A, 802.11 ad) and revolutionary additions (cm- / mm-wave)
- It’s all about data (speed and capacity)

URLLC

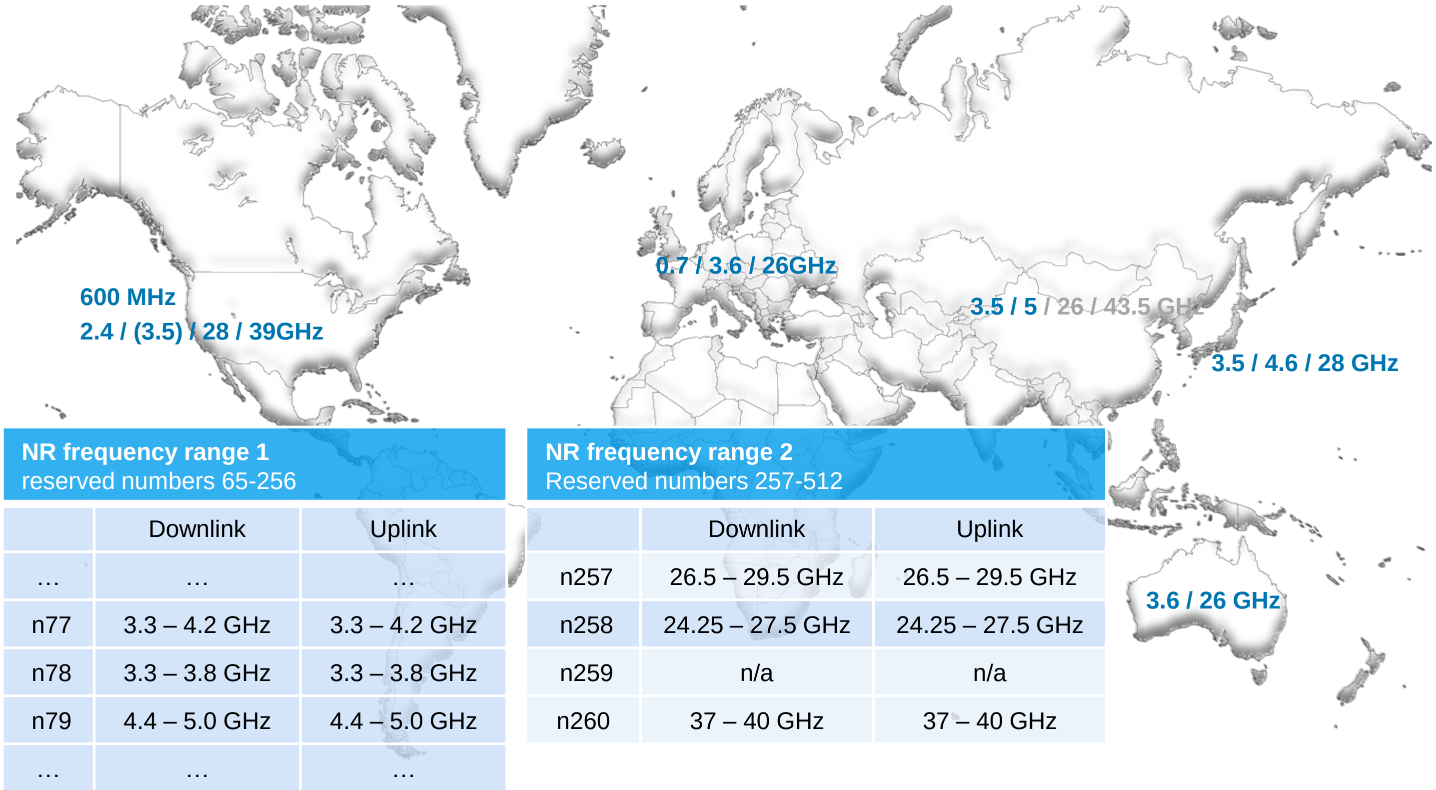
- A significantly enhanced and diverse ecosystem (operators (?), manufacturers, verticals, certification not existing (yet))
- Existing technologies do not provide sufficient performance
- It’s all about reliability and security (data and capacity)

Earliest expected 5G commercial launch dates (mobile or FWA)



Source: GSA Evolution from LTE to 5G report, November 2018

Frequency trends for 5G



NR frequency range 1
reserved numbers 65-256

	Downlink	Uplink
…	…	…
n77	3.3 – 4.2 GHz	3.3 – 4.2 GHz
n78	3.3 – 3.8 GHz	3.3 – 3.8 GHz
n79	4.4 – 5.0 GHz	4.4 – 5.0 GHz
…	…	…

NR frequency range 2
Reserved numbers 257-512

	Downlink	Uplink
n257	26.5 – 29.5 GHz	26.5 – 29.5 GHz
n258	24.25 – 27.5 GHz	24.25 – 27.5 GHz
n259	n/a	n/a
n260	37 – 40 GHz	37 – 40 GHz

Europe
- 700 MHz
- 3.4 - 3.8 GHz
- 24.25 - 27.5 GHz

China
- 3.3 - 3.6 GHz
- 4.8 - 5.0 GHz
- 24.75 - 27.5GHz (study)
- 37 - 43.5 GHz (study)

US
- 600 MHz
- 2.4 GHz
- [CBRS band (3.5GHz)]
- 27.5 - 28.35 GHz
- 37.0 - 40 GHz

Australia
- 3.6 GHz
- 26 GHz

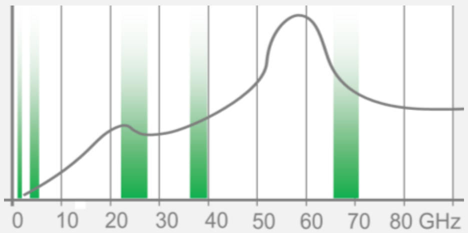
Korea
- 3.42 - 3.7 GHz
- 26.5 – 28.9 GHz

Japan
- 4.4 - 4.9 GHz
- 28 GHz

5G Key Technology Components

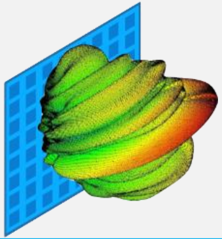
NR builds on four main pillars

New Spectrum



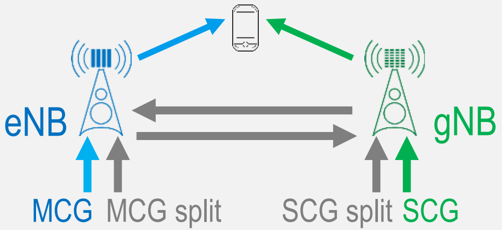
- < 1GHz
- ~ 3.5 GHz
- ~ 26/28/39 GHz

Massive MIMO & Beamforming



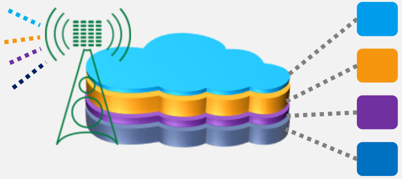
- Hybrid beamforming
- > 6GHz also UE is expected to apply beam steering

Multi-Connectivity



Initially based on Dual Connectivity with E-UTRA as master

Network flexibility - virtualization



- Flexible physical layer numerology
- Network Slicing
- NFV/SDN

5G New Radio (NR) offers a flexible air interface

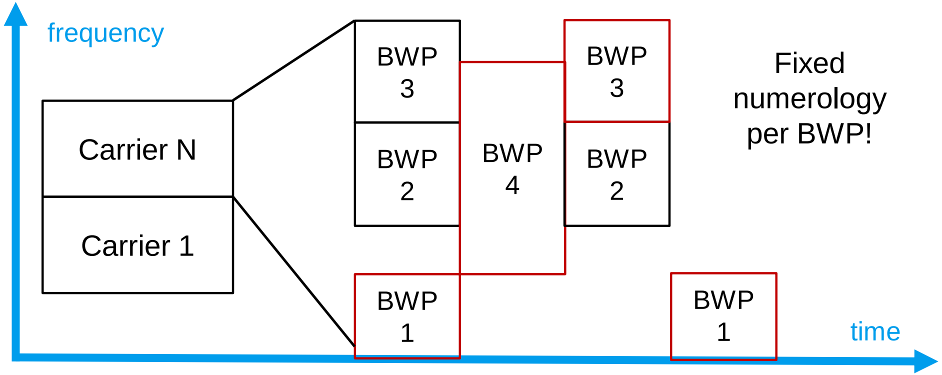
Summary of key parameters – R&S view in bold

Parameter	FR1	FR2
Carrier aggregation	**LTE (e.g. 3CC) + 1CC NR**	**LTE + 1CC or 2CC NR**
Bandwidth per carrier	5, 10, 15, **20**, 25, 30, 40, 50, 60, 80, 90, **100**MHz	50, **100**, **200**, 400 MHz
Subcarrier spacing	15, **30**, 60 kHz	60, **120**, 240 kHz
Modulation scheme	**QPSK up to 256QAM**; uplink also supports π/2-BPSK (only DFT-s-OFDM)	**QPSK up to 64QAM**; uplink also supports π/2-BPSK (only DFT-s-OFDM)
Radio frame length	10ms	
Subframe duration	1 ms (alignment at symbol boundaries every 1 ms)	
MIMO scheme	DL: **SISO, 2x2 MIMO** or 4x4 MIMO**;** UL: **SISO** or 2x2 MIMO	DL: **2x2 MIMO** UL: **SISO** or **2x2 MIMO**
Duplex mode	**TDD**, FDD	**TDD**
Main frequency bands	**3.3 to 3.8 GHz**, 4.4 to 5 GHz, 5.9 to 7.1 GHz	**24 to 29 GHz**, 37 to 43.5 GHz
Access scheme	**DL: CP-OFDM; UL: CP-OFDM**, DFT-s-OFDM	

Bandwidth Parts (BWP)

Motivation: support various UE Bandwidth, switch between numerology, power mode optimization

BWP: specific allocation of a certain frequency spectrum within the overall carrier bandwidth
- in either direction, uplink and downlink
- contiguous subset of physical resource blocks



Up to four BWP in downlink/uplink per UE

Single BWP at a given time (*Active BWP*)
- No reception of PDSCH or PDCCH outside DL BWP
- No Transmission of PUSCH or PUCCH outside UL BWP

BWP can be switched by RRC, DCI or Timer

Summarizing effecting factors

- Multi mode / multi band support
- Much higher bandwidth
  - DPD becomes even more necessary
- Higher frequencies > 6 GHz, simultaneous use of RF and mmWave links

- New waveforms have profound effects on amplifiers, switches …

- Massive MIMO / beamforming
- High integration of all components incl. antennas
- Tight phase requirements and time alignment for data converter, clocks etc to drive the beamforming antennas

- Speed upgrades for backbone -> faster SerDes / higher speed clocks

From technology to component

Beamforming and phased array

Higher frequencies: path loss issues

Higher frequencies = higher attenuation
Higher frequencies = smaller antennas

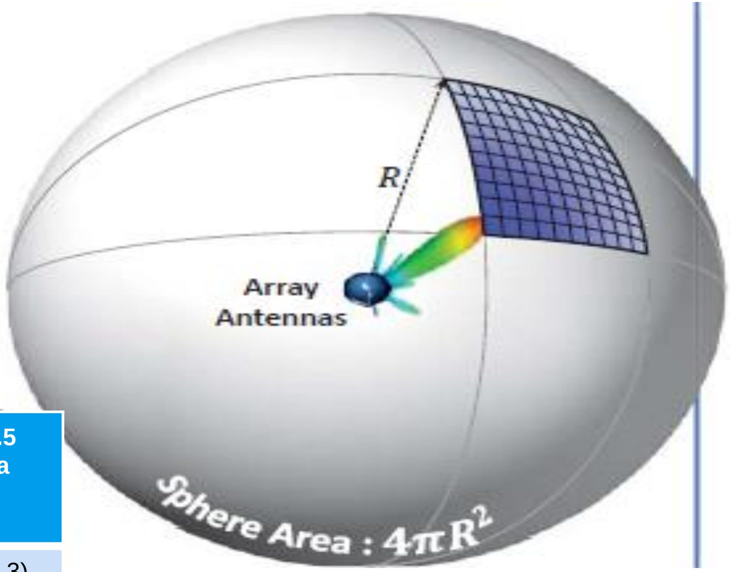
Friis equation

$$\frac{P_{Rx}}{P_{Tx}} = G_{antenna}\left(\frac{c}{4\pi f d}\right)^{\gamma}$$

Beamforming

EXAMPLE
@ 28 GHz:

PathLoss 28 GHz	γ = 2 Free Space	γ = 1.6 to 1.8 Indoor LOS	γ = 2.7 to 3.5 Urban Area
1 m	- 61,4 dB	- 52 dB (k=1,7)	-92,1 dB (k = 3)
10 m	- 81,4 dB	-69 dB	-122,1 dB
100 m	- 101,4 dB	-86 dB	- 151,1 dB
1000 m	- 121,4 dB	-103 dB	- 181,1 dB

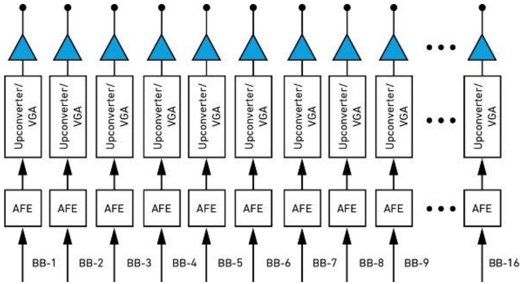


γ = path loss exponent

Beamforming implementation

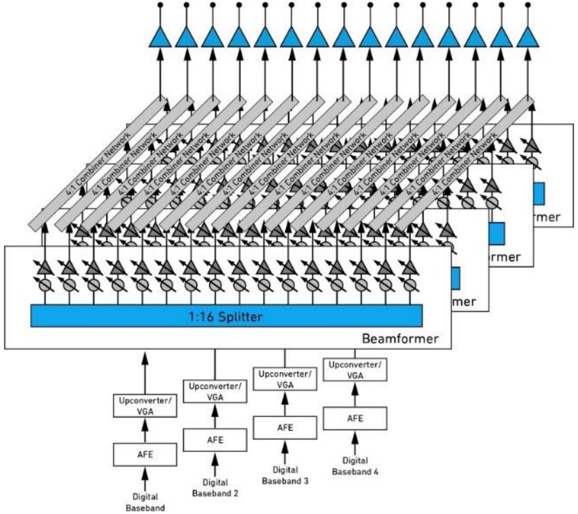
Digital

- Less elements, typ. up to 128
- Straight forward
- Requires more power per element



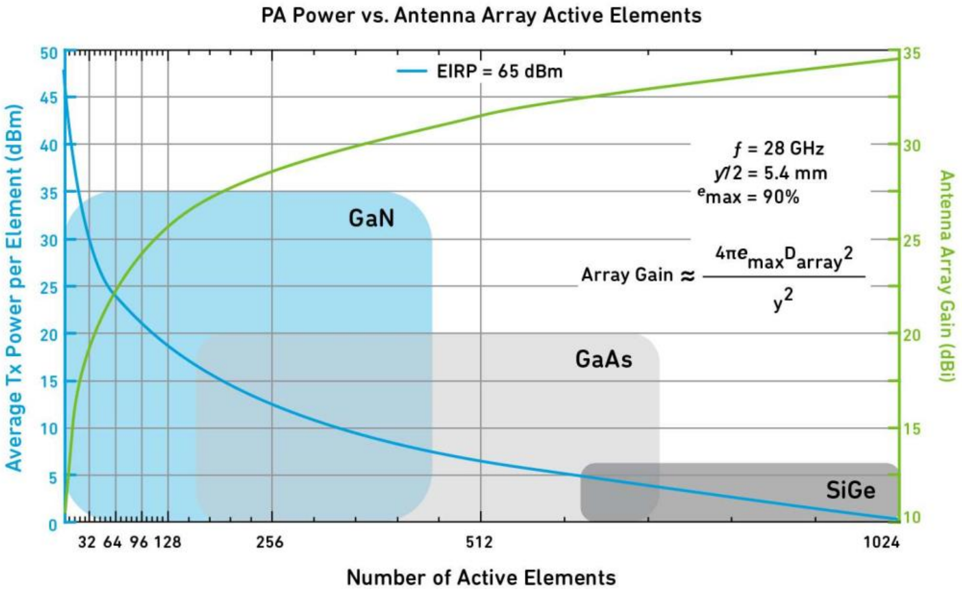
Hybrid

- More elements, up to 1000 and more
- Complex controls
- Less power per element



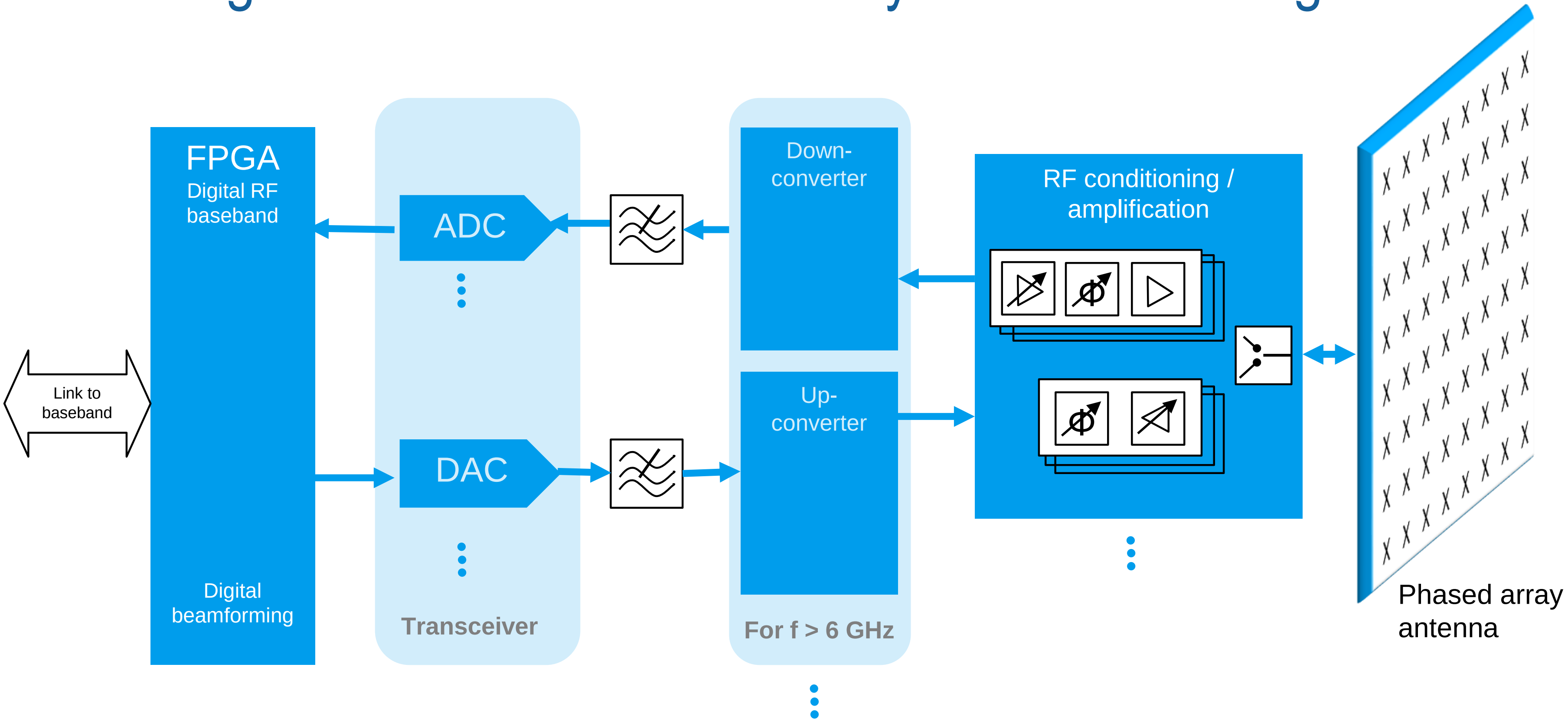
Beamforming: hybrid or digital?

- Battle of technologies for mmWave applications
  - Hybrid vs Digital beamforming
  - GaN vs GaAs vs SiGe



Optimum RFFE technology
vs array size for fixed 65 dBm EIRP

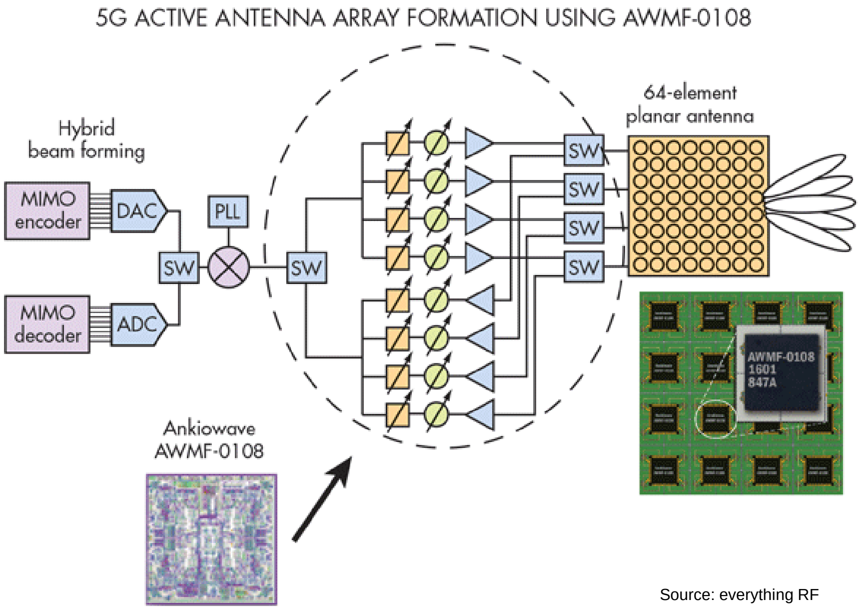
Block diagram of the RF section for hybrid beamforming



Integrating beamforming

- Analog beamforming: phase shifter and level control
- Highly integration
- Integrated PAs or separate
- Less gain per PA needed, but many PAs as every path needs a PA

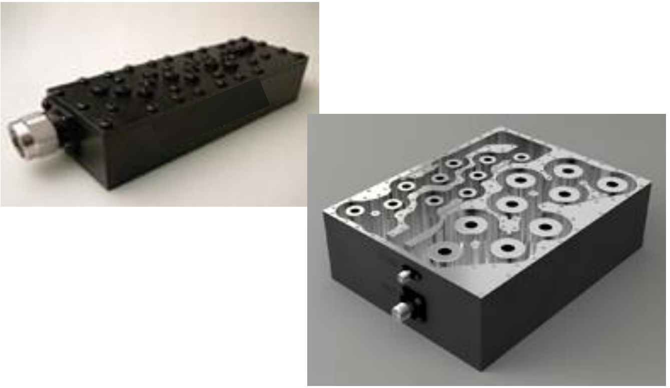
- Challenge for pure PA companies!



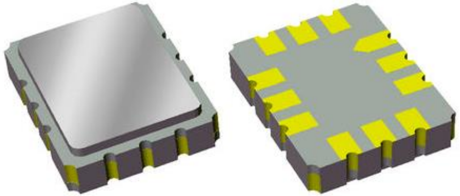
Source: everything RF

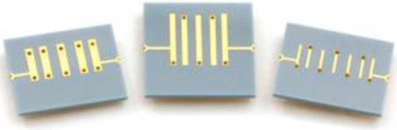
RF filters – still needed?

- High power: Cavity filters
- Significant size: 180 x 88 x 62 mm @ 750 MHz

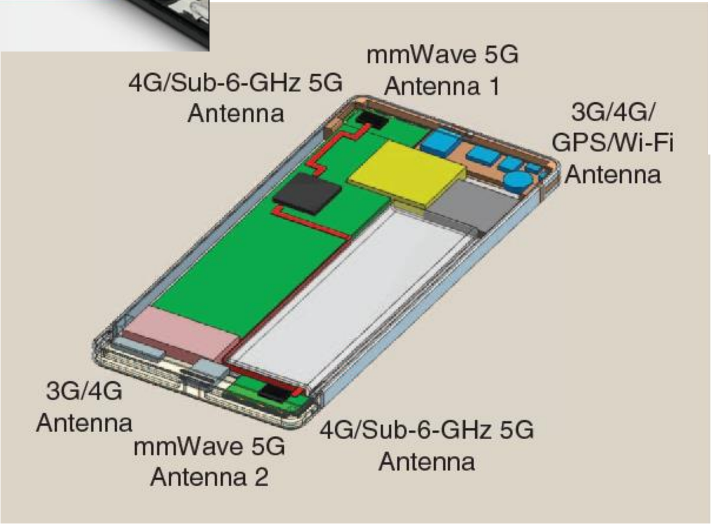


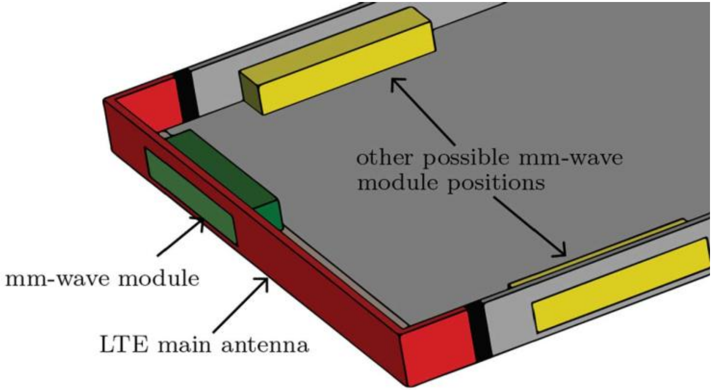
- Beamforming approach: smaller, less power, more cost efficient
- BAW and Ceramic filters are attractive





Evolution in mobile antenna design: developments





Amplifiers

PA technology

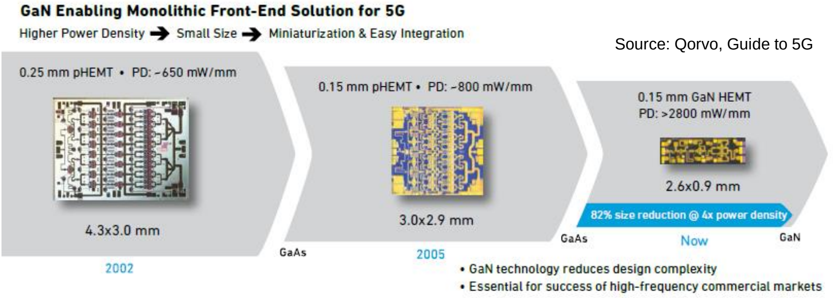
Latest technology: GaN
Started as government funded technology for A&D

- Power density: 8 times of GaAs
- Efficiency: 40 to 70 % up to GaAs

- Higher integration possible thanks smaller package and higher power density
- Excellent suited for wideband applications
- But: DPD is a must have feature for high efficiency

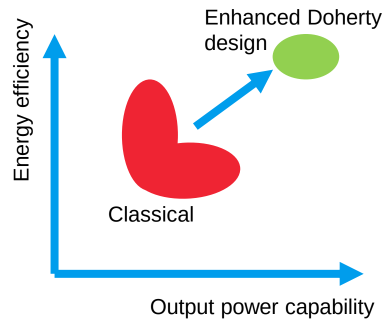
TABLE 1
GAN MARKET SHARE STRATEGY ANALYTICS, JANUARY 2015

	Military Segment	*Total Worldwide*
Wolfspeed	19%	25%
Qorvo	24%	22%
Sumitomo	17%	22%
Raytheon	13%	7%
Northrop Grumman	11%	6%
UMS	6%	6%
Others	10%	12%



Source: Qorvo, Guide to 5G

Doherty designs – background



Facts

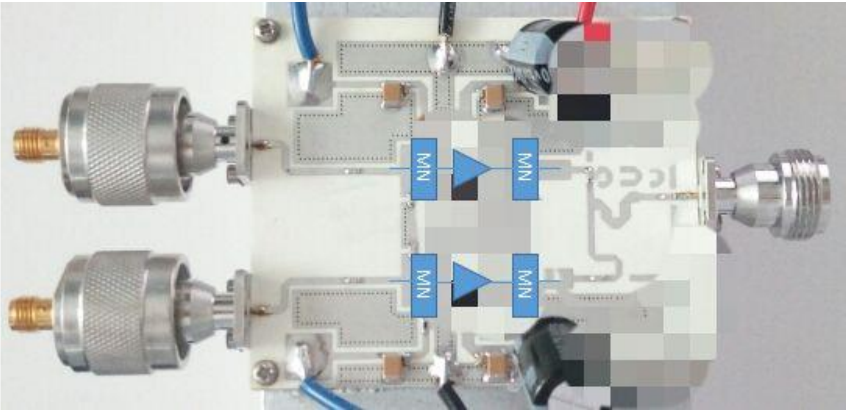
- Invented almost 100 years ago
- Efficiency enhancement method
- Linearity-preserving
- Two (or more) amplifiers that interact through a special combining network

Applications

- Mostly for below 3 GHz until now
- Dominates on base station infrastructure

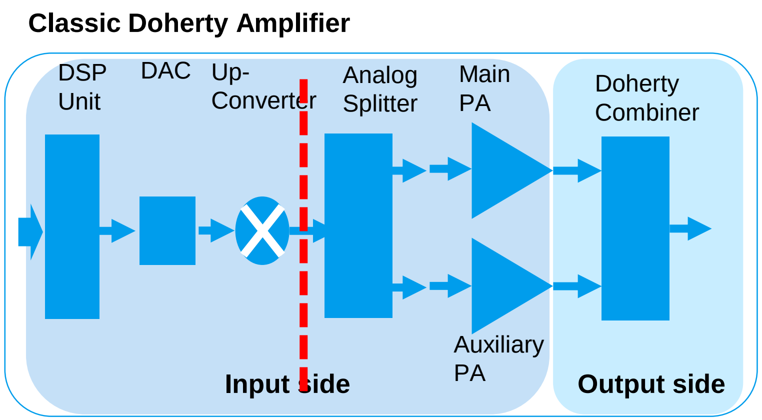
New Frontier

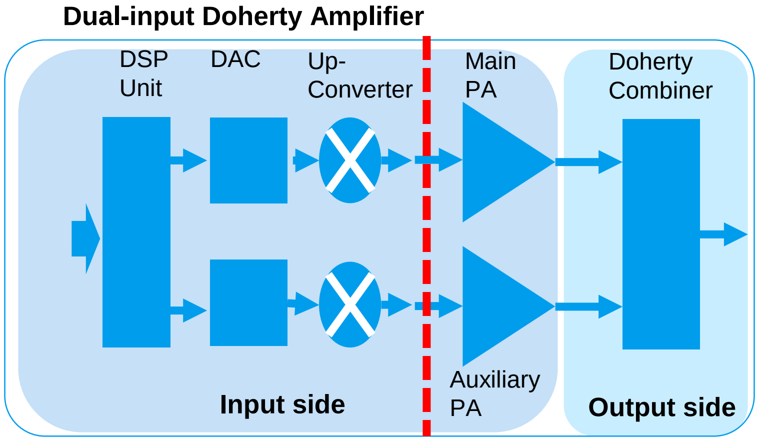
- Higher carrier frequencies, wider BW
- 5G in mmW, SatCom (Ku-, Ka-bands)



Doherty designs – background

- **Input Side – Input Split**
  - Source of differentiation
    - Performance
    - Cost
  - Many split architectures
    - Fixed RF input splitter
    - Programmable RF input splitter
    - Dispersive input splitter
    - Dual-input
- **Output Side – Doherty Combiner**
  - Eventual performance limits





Test solutions

R&S test solution

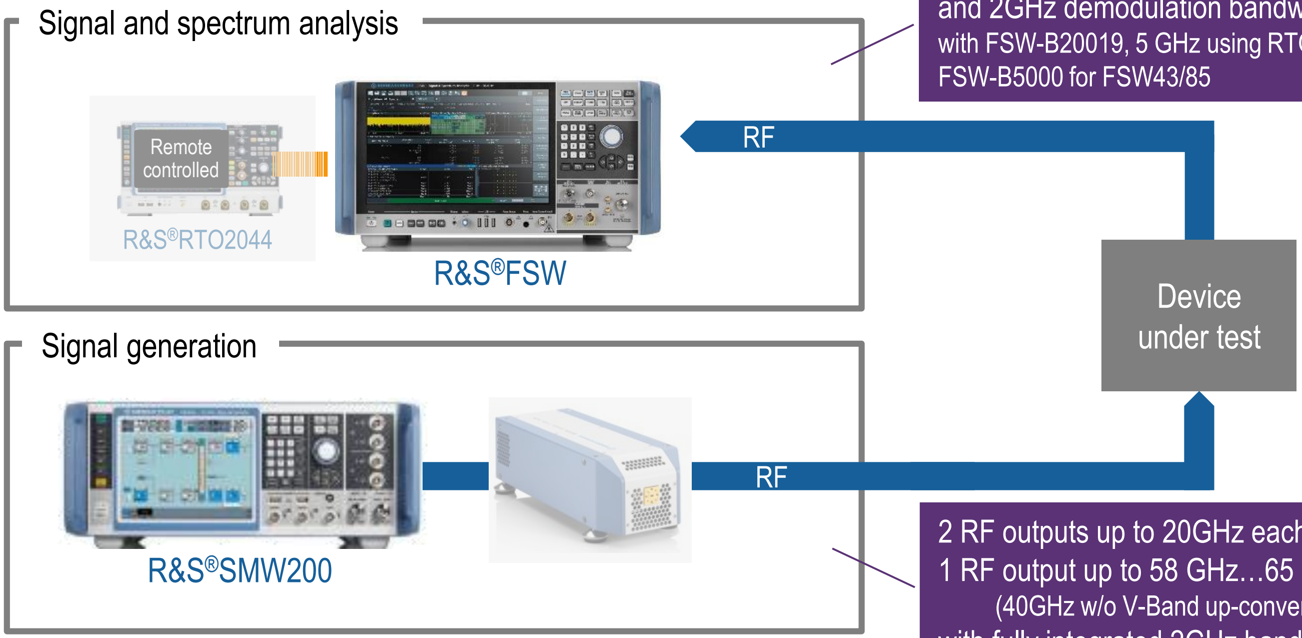
Network analysis as basis for amplifier test

- Standalone VNA
  - Frequency coverage
  - Gain, gain compression, compression point, saturated power
  - Power consumption/gain
  - Efficiency / PAE
  - Harmonics
  - Matching
  - Small signal S parameter
  - Pulsed S parameter (ZNA)
  - Noise figure
  - Intermodulation

R&S test solution

Wideband signal generation and signal analysis

Analysis up to 90 GHz w/o external mixer and 2GHz demodulation bandwidth (internal with FSW-B20019, 5 GHz using RTO2064 and FSW-B5000 for FSW43/85



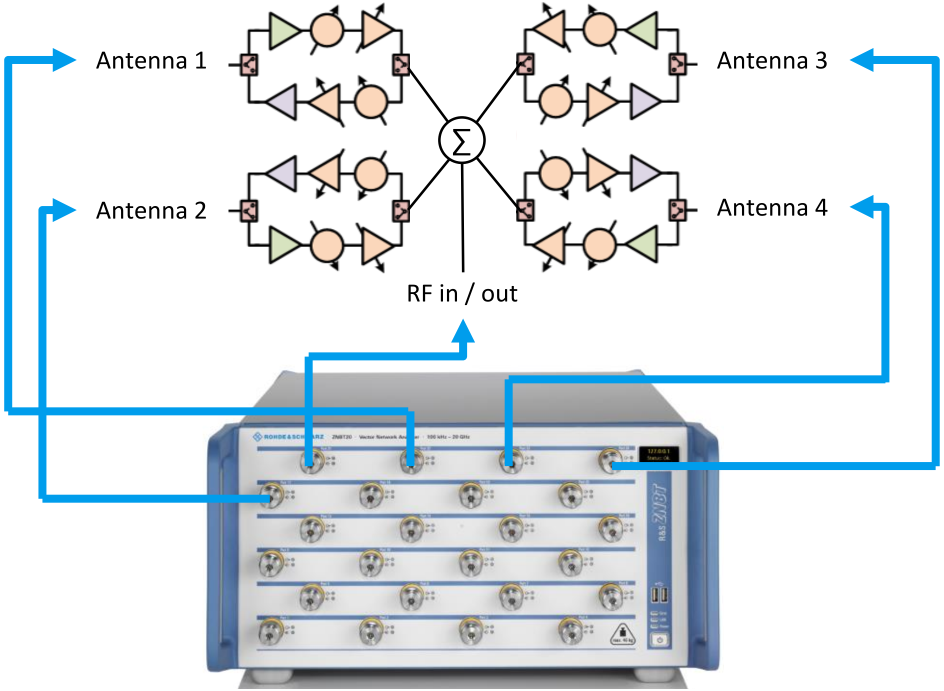
2 RF outputs up to 20GHz each or
1 RF output up to 58 GHz…65 GHz
(40GHz w/o V-Band up-converter)
with fully integrated 2GHz bandwidth

Mixer test
Optimal solution: ZNA

- **Relative phase measurements** on mixers thanks to phase-coherent and phase-repeatable sources without having to use a reference mixer – important for beamforming phased array applications

- Parallel measurement on RF and IF gives 2x speed improvement for conversion loss measurement
- Swept LO measurements
- Intermodulation on mixer with frequency and level sweeps
- Group delay plus AM/AM and AM/PM conversion

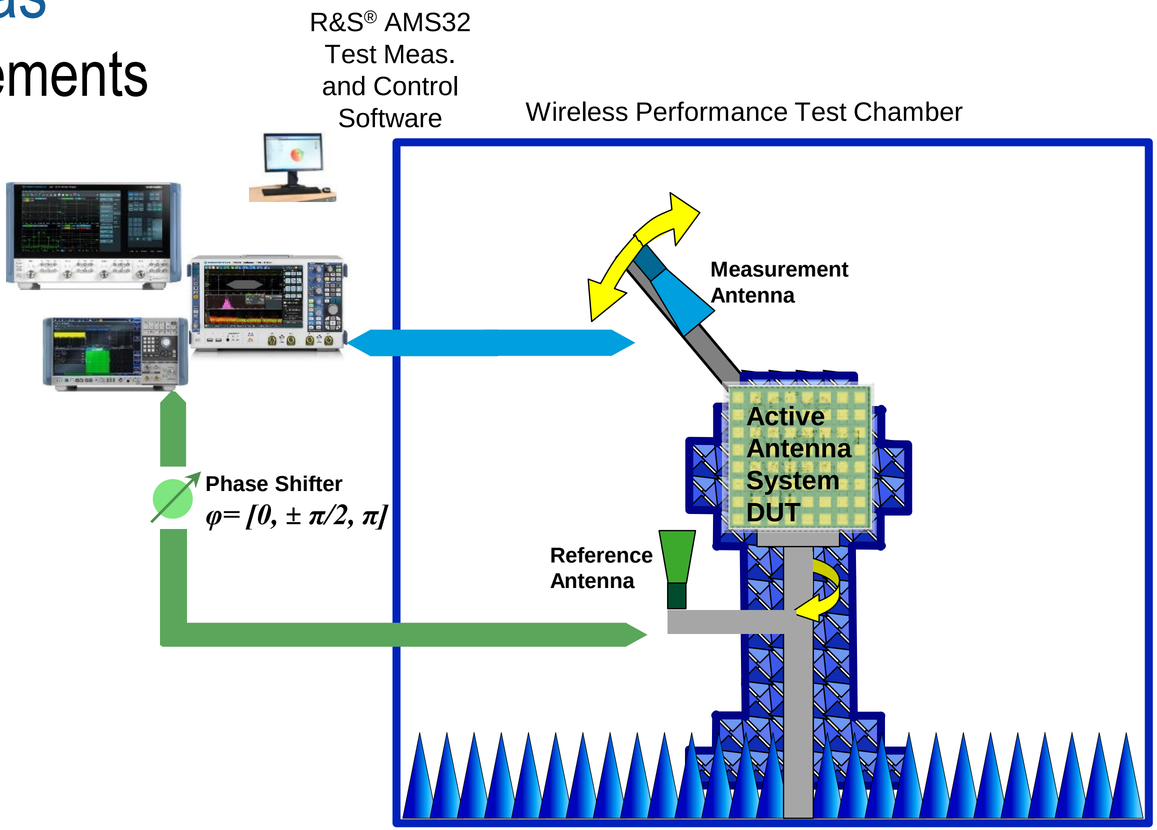
Test beamformer in one shot



Testing of active antennas
OTA beamforming measurements

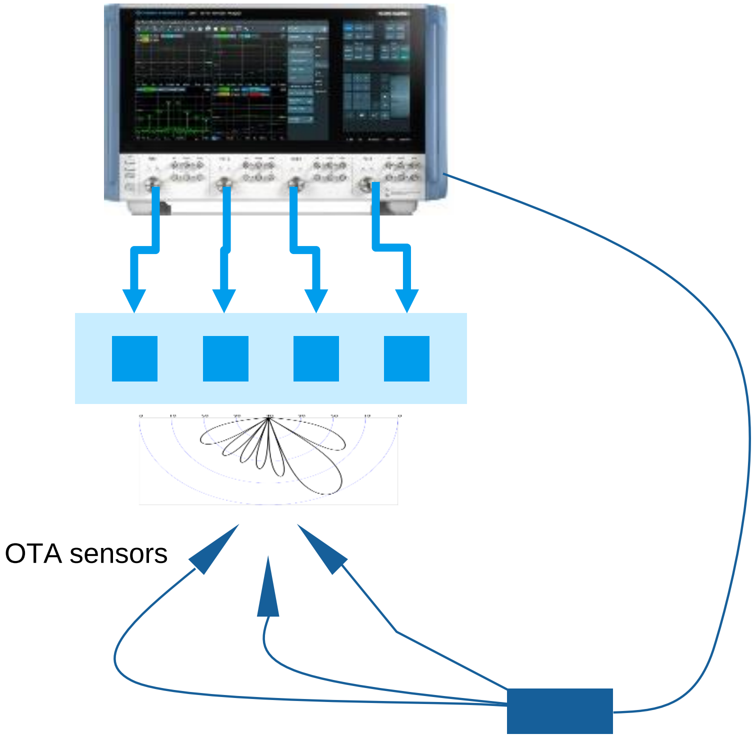
- Antenna gain
- Array antenna gain
  10 LOG N + single antenna gain

- EIRP
  Effective Isotropic Radiated Power
  = Pt * Gt
- Array EIRP = Pe + Ge + 20 LOG N

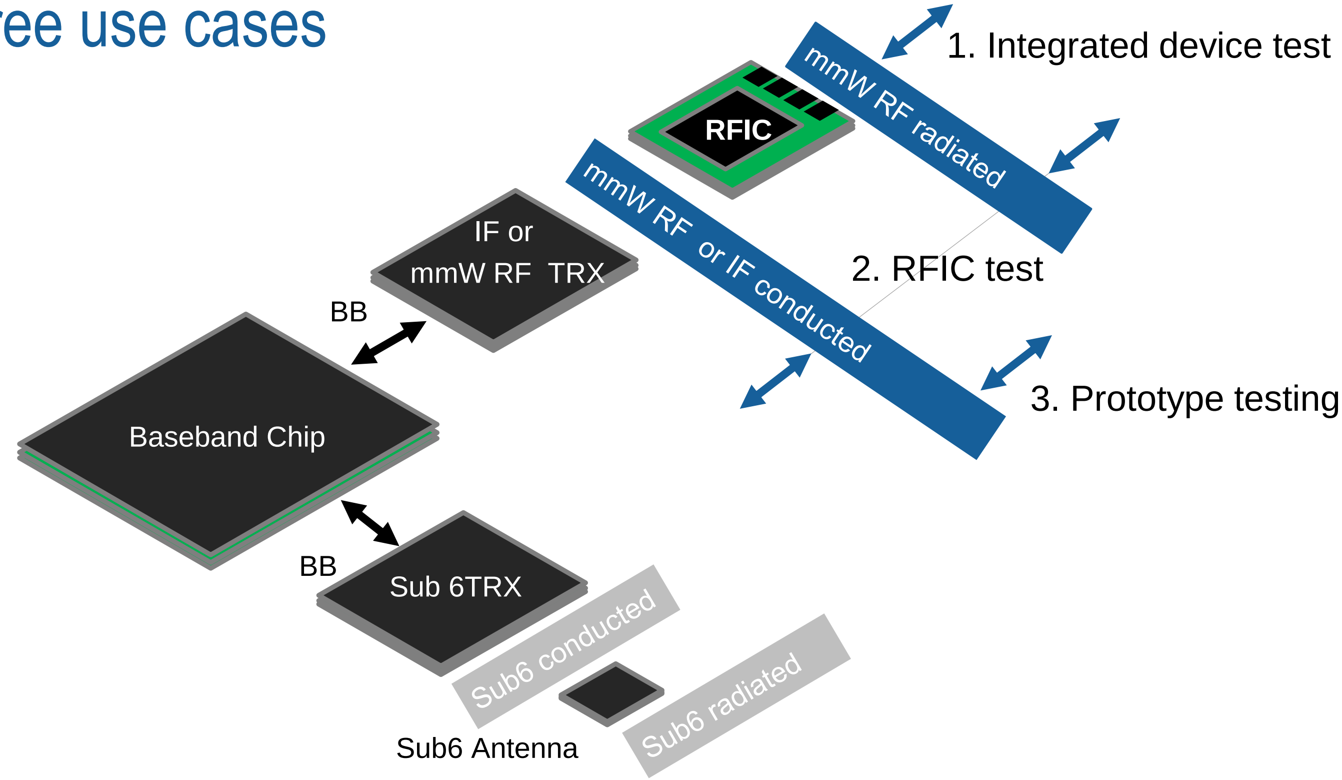


Beamforming calibration
TX beamsteering

- VNA R&S ZNA offers 4 phase repeatable and adjustable sources
- Combine with 3 OTA sensors
- Measure at 0°, +45°, -45°
- Done



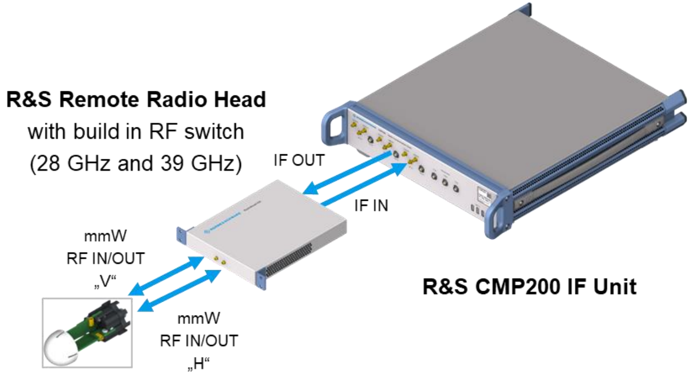
5G mmW analog test interfaces
Three use cases



Fully integrated solution for RF testing of 5G FR2 (mmW)
Conducted or OTA

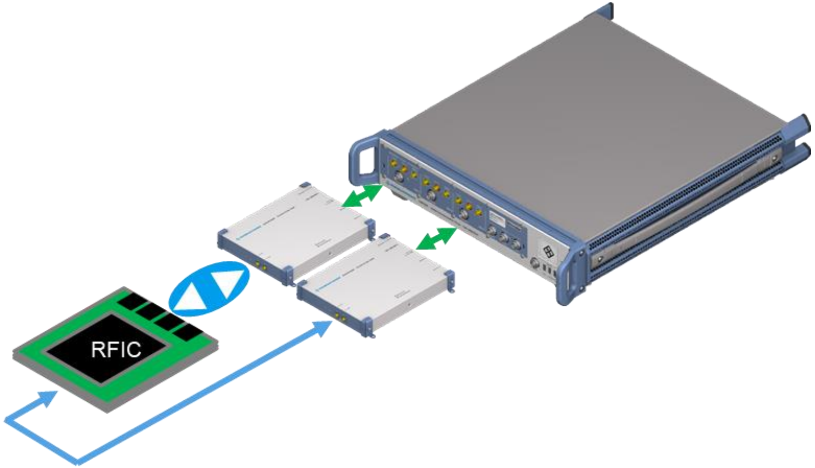
- CMP as non-signaling tester can be a good alternative for 5G RFIC, mmWave components
- Interface conducted or OTA on RF and conducted IF
- Multiple channels
- Performance good enough for handset components

- Matching OTA production shielded “cube” will be added

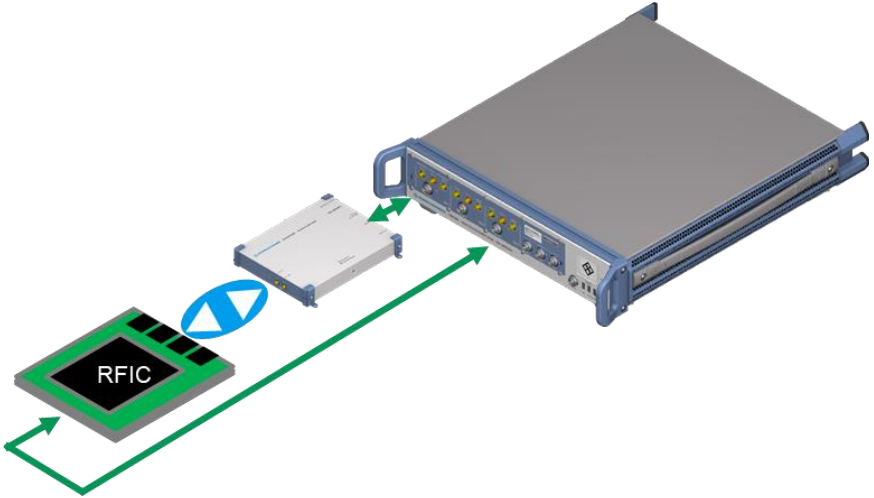


RFIC RF parametric testing

- mmW conducted <-> mmW radiated



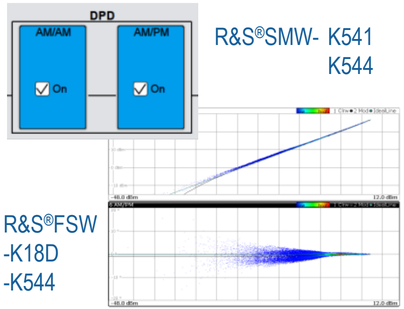
- IF conducted <-> mmW radiated



R&S test solutions to develop and implement 5G NR products

Component Characterization

PA characterization and calibration



R&S®SMW- K541
K544

R&S®FSW
-K18D
-K544

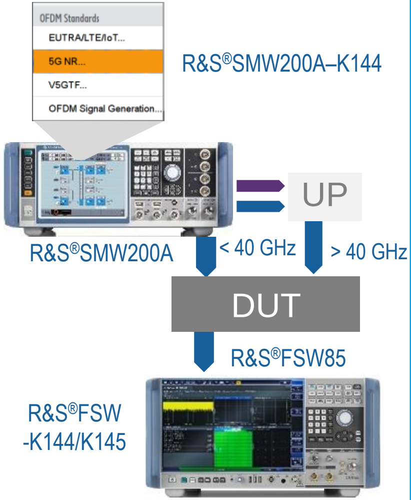
Network
Analyzer

R&S®ZNA

R&S®ZVA

Direct measurements up to 110 GHz

RF development



R&S®FSW
-K144/K145

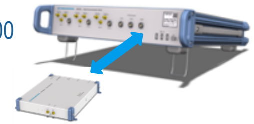
- 40 GHz signal generation
- 90 GHz signal analysis
- 2 GHz bandwidth support
  (FSW: 5GHz with RTO2064 and B5000)

5G NR Device Testing

Testing of 5G NR devices in non-signaling mode

R&S®CMW100
(Sub6)

R&S®CMP200
(mmW)



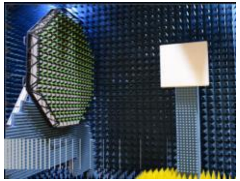
Testing of 5G NR devices in signaling mode

R&S®CMX500

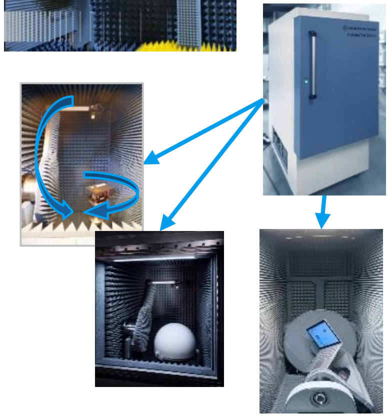
R&S®CMWFlexx
supporting LTE for NSA operation

OTA solutions

R&S®PWC200



R&S®ATS1xxx



R&S®ATS800B

R&S®TS7124

"If you want to go fast, go alone.
If you want to go far, go together!"

African proverb